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NASA Contractor Report 2956

Significant Achievements in the Planetary Program - 1976 - 1977

James W. Head, Editor

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Introduction

The annual meeting of the Planetary Geology Program Principal Investigators was held May 23-25, 1977 in St. Louis, Missouri at the McDonnell Center for the Space Sciences at Washington University. The papers presented there represented the high points of research carried out in the Planetary Geology Program of NASA's Office of Space Science, Division of Lunar and Planetary Programs. The purpose of this paper is to present a summary of the research and significant developments in Planetary Geology for this year, based on the oral presentations at this meeting. Additional information on the reported research, and reports of work in planetology during the past year, are contained in the abstract volume prepared for the annual meeting and are available as "Reports of Planetary Geology Program, 1976-1977" (NASA TM X-3511; available from the National Technical Information Service, Springfield, VA 22161; price $9.25) and "A Bibliography of Planetary Geology Principal Investigators and Their Associates, 1974-1976" (NASA TM X-74315; available from the Planetary Geology Program Office, NASA Headquarters, Washington, D.C. 20546).

Material for this paper was drawn from summaries prepared by session chairmen at the annual meeting (Donald Wise, Univ. Mass.; James Pollack, NASA-Ames; Bruce Hapke, Univ. Pittsburgh; Dag Nummedal, Univ. South Carolina; R. Greeley, Univ. Santa Clara and NASA Ames; Ray Arvidson, Washington Univ.; Sean Solomon, MIT; Joe Veverka, Cornell; Fraser Fanale, JPL; and Henry Holt, USGS).

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Editor
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Constraints on Solar System and Planetary Formation

Papers presented in this session covered topics ranging from broad cosmogonic issues to detailed studies of physical or chemical processes that may have been important during the early history of the solar system. Two very different models for the formation of the solar system were analyzed by A. G. W. Cameron (Harvard College Observatory), who emphasized fluid dynamical processes, and by H. Alfven and D. A. Mendis (Univ. Calif.-San Diego), who laid great importance to electromagnetic mechanisms.

A central concept to Cameron's model of solar system formation is the existence of large gaseous protoplanets both in the inner and outer portions of the solar system. The motivation for these objects comes from his analysis of the stability characteristics of the primordial solar nebula, which showed that it becomes unstable at all locations to global instabilities that result in the formation of rings. It seems plausible that the rings, in turn, will break into large gaseous blobs. Cameron and his associates are studying the thermodynamic properties and evolutionary history of these gaseous protoplanets. Their results to date suggest that these objects initially slowly contract, with their central regions becoming progressively warmer. At some point, the temperature becomes high enough near the center for primordial dust grains to go from a solid state to a liquid state. Furthermore, because grain opacity controls the temperature structure at this stage, the central

region will tend to hover near the part of the phase diagram where liquids are permitted. Cameron expects that liquid particles will rapidly coalesce, resulting in large particles, which fall to the center of the object to form a large heavy element core. This process provides an explanation for the heavy element cores present in the outer giant planets of today as well as for the creation of the terrestrial planets. The formation of the sun, through gas inflow in the solar nebula, tidally disrupts the gaseous protoplanets in the inner solar system before they can become compact enough, but this process does not effect the protoplanets further out. The end result, according to Cameron, is a set of compact gaseous planets with central cores in the outer solar system and a set of central cores -- the terrestrial planets -- which have been stripped of their gaseous envelopes.

In their earlier work H. Alfven and D. Mendis stressed the role of electromagnetic forces in ionizing the primordial solar nebula and in solving the angular momentum problem of the current solar system -- most of it resides in the planets' orbits rather than the sun's rotation -- by providing a means of transferring angular momentum outward in the primitive solar system. In their more recent work they have concentrated on a later time period, one that encompasses the formation of planets and their early history. They envisioned that discrete objects form from the solar nebula as a consequence of a radial bunching of planetesimals; i.e., the creation

of a "jet-stream". Simulations of such jet-streams indicate that collitions between the particles leads to the formation of a flat disk structure. Presumably this represents an intermediate stage in the creation of planets and asteroids and may be exemplified by the current rings of Saturn and Uranus.

Alfven and Mendes have also studied by effect of more violent collisions on the later history of solar system objects. The destructive effects of collisions between members of the asteroid belt depends both on their orbital eccentricity and position in the belt. These dependences may be relevant to the creation of gaps in the belt and to compositional zonation. Once Jupiter forms it will perturb material from the outer region of the solar system to the inner part and thereby subject the terrestrial planets and asteroids to a period of "catacylsmic" bombardment.

C. Sagan and R. Isaacman (Cornell) have studied solar system formation in a more general way. They have utilized a highly simplified model proposed by Dole to study the dependence of planetary configuration on the properties of the primordial solar nebula. According to this scheme, planets are formed by placing "nucleation" centers within the nebula and allowing them to collect all the material they come into contact with. Sagan and Isaacman find that they are able to generate a variety of planetary systems, which range from multiple star systems with accompanying planets, to systems having only Jovian type planets at large distances, to

single stars with only asteroids surrounding them. A small subset of the cases studied led to systems resembling our own. The important variables in controlling the nature of the planetary system include the orbital eccentricity of the nucleation centers and the distribution of gas and dust. The authors conclude that planetary systems can be easily formed under a variety of conditions and are therefore plentiful in our galaxy.

K. Goettel (Washington University) has adopted the equilibrium condensation sequences of Lewis and Grossman to estimate the mineralogy of the terrestrial planets. According to this concept, these bodies formed at different positions and therefore different temperatures in the solar nebula. Equilibrium thermodynamics is used to specify the composition of the condensation products. As a first approximation, no radial mixing of materials is considered and a single condensation temperature is specified for each planet. As was known before, the gross properties of the terrestrial planets, such as their densities, that are derived from this model are consistent with their observed characteristics. Goettel's calculations provide a more definitive picture of the planets' composition, their zonation, and the amount of heat-producing radioactive elements. He finds that much of Mercury consists of a metallic iron core, with a mantle made primarily of fosterite. Also because Mercury did not retain potassium, its radioactive heat sources per unit mass are smaller than for the other

terrestrial planets. Hence little global tectonic activity is expected on Mercury. As one progresses out in the solar system more iron is oxidized and more water is incorporated into the condensed material. Venus, the Earth, and Mars are all expected to have retained enough radioactive elements for global tectonics to have occurred during part or most of their history.

C. Federico (Italian Consortium for Planetary Studies) is studying the earliest phases of planetary formation by calculating the initial growth of particles starting with interstellar dust grains. Only a very modest growth is found for solid particles when growth through mutual collisions is considered because of their low sticking probabilities. A somewhat larger growth takes place in portions of the nebula which are hot enough for the grains to become liquid and hence have near-unit sticking probabilities.

R. Smoluchowski (Princeton) is examining the effect of solid phase changes on the physical properties of interstellar dust grains. For example, depending on its formation conditions, water ice can have four different solid phases. These phases differ in their densities and surface characteristics. The latter influences the rate and nature of molecular reactions that occur on their surface, which can strongly influence the gas composition. Also, ionization of these particles by stellar ultraviolet radiation can effect the nature of the surface molecular reactions. But, the degree of ionization may be heavily influenced by the solid phase of the grains.

Constraints on the Characteristics of Planetary Interiors

J. Wood (Smithsonian Astrophysical Observatory) discussed the constraints imposed by present knowledge of the structure and composition of the moon, derived largely from a combination of studies on returned samples plus orbital and seismic data. He suggested that the lunar "Moho" equivalent at a depth of 60 km is the base of a layer of plagioclase crystals floated to the top of a formerly melted surface layer 300-500 km thick. The lower limit of this melted layer is the break between the upper and middle lunar mantle. He further suggested that a break at 25 km is unique to the mare locations and represents the base of a layer of Fra Mauro noritic fragments beneath a thin layer of mare basalt. The lower mantle with its seismic activity and strong seismic attenuation was suggested as equivalent to the Earth's lithosphere-asthenosphere boundary. The core could be a eutectic mixture of Fe and S with a limiting radius of 300 to 350 km or less than 1% of the lunar volume as based on density and moment of inertia considerations.

S. Solomon (MIT) presented a general model for planetary evolution and volcanism entitled "Heat, Stretch, and Erupt". The model suggests that the early stages of a planet's history involved heating and core formation with consequent crustal stretching and outpouring of basaltic floods. Eventually cooling takes over with consequent shrinkage and a termination of the era of massive basaltic outpourings. He presented computer models based on a

variety of initial conditions showing a wide range of possibilities for the time of this transition for the terrestrial planets. Their surface geology suggests that Mercury has undergone a long period of the cooling-contraction stage; that the heating stage continued until relatively late for Mars; and that an approximate balance between lithospheric contraction and interior thermal expansion has characterized the moon.

S. Peale and A. Boss (University of California, Santa Barbara) discussed limits on the viscosity of the core of Mercury imposed by its present 3/2 resonance ratio between the orbital period and the spin period. The evidence for the fluid core is the magnetic field discovered by Mariner 10. To reach its present 3/2 resonance, Mercury had to pass through other resonances, the most limiting being the one at a ratio of 2. To escape this resonance state using only laminar flow in the core, the Q values of the core must be on the order of 100 and the viscosity about .01 cm^2 sec, a surprisingly low value. If the flow were turbulent, Q could be reduced by a factor of 5 or more. They concluded that more data are needed on the turbulence problem in this boundary region before the viscosity constraints can be made more definite.

R. Phillips (Jet Propulsion Laboratory) discussed whether the non-isostatic support of Tharsis Ridge of Mars, approximately 1/3 of the total Tharsis gravity anomaly, is due to static or dynamic mechanisms. Elastic models require shear stresses on

the order of 100 bars in the lower mantle. The evidence of long term volcanism on Tharsis provides some lower temperature limits for the underlying mantle which in turn place severe limits on the finite strength and long term relaxation time of the mantle. Phillips finds that support of the Ridge by long term finite strength of the mantle is not possible. Similarly, the order-of-magnitude larger stresses required for elastic support of the Ridge by the lithosphere are also unlikely. He tentatively concludes that some dynamic process in the Martian mantle must be responsible for the support of at least part of Tharsis Ridge.

Y. Nakamura (University of Texas, Galveston) discussed the Viking Seismology experiment. He pointed out that the Viking seismometer was a very effective wind gauge in recording the vibrations of the space craft with high fidelity. Peak seismic signals showed good correlation with periods of high wind speed recorded by other instruments. Of the eight "seismic" events recorded, six correlated with wind gusts. The remaining two have been widely publicized in the popular press as "marsquakes". These two events produced records similar to the other six, but unfortunately there were no other wind recording devices working at those times. The conclusion is that there have been few or no "marsquakes" recorded and that Mars is less active seismically than the earth with an 85% confidence level.

Photogeologic Constraints on Planetary Evolution

The evolution of a planetary body is often expressed by changes in the planet's surface. Conversely, the history of a planetary surface serves as a strong constraint on the evolution of the planet's interior. In papers devoted to study of one or more of these constraints, several themes persisted: the relative ages of plains units, both for a single planet and among several planetary bodies; the origin of plains units; and the character, timing and mechanism of tectonism and volcanism on Mercury, Mars, and Venus.

M. C. Malin (Jet Propulsion Laboratory) summarized the evidence for endogenic resurfacing processes contemporaneous with heavy bombardment on Mars, Mercury and the Moon. On Mercury, the range of preservation of large craters on the intercrater plains supports the idea that these units were emplaced throughout the heavy bombardment. On Mars, the cessation of intercrater plains formation, probably a volcanic process, coincided approximately with the decline in volatile-related erosional processes (channeling, fretting, production of chaotic terrain). Thus Malin linked intercrater plains formation on the terrestrial planets, and atmospheric outgassing on Mars, to the heavy bombardment, perhaps through impact heating.

R. G. Strom (University of Arizona) presented arguments for a volcanic origin, contemporaneous with heavy bombardment, for

both the intercrater plains on Mercury and the pre-Imbrium Pitted Plains on the Moon. For both regions, a deficiency of craters ≤ 40 km in diameter with respect to heavily cratered terrain indicates that the intercrater plains are generally somewhat younger. The pitted plains on the Moon are distinct from probable basin ejecta deposits by their relative abundance of fresh craters and paucity of more degraded ones. The more widespread distribution of intercrater plains on Mercury than the Moon may be the result of extensive volcanism during a pronounced radial expansion of Mercury due to formation of the large core.

L. A. Soderblom (USGS) used the density of craters 5 to 10 km in diameter as a mapping tool to study the range of ages of smooth plains deposits on Mercury, Mars and the Moon. Craters of such a size are large enough not to be constantly erased by impact or eolian erosion but small enough to be obliterated by plains-forming resurfacing. Mercurian smooth plains have only a 3 to 1 variation in the density of such craters, compared to 5 to 1 for the Moon and 20 to 1 for Mars. Soderblom concluded that the Mercurian plains formed over a narrower time span than did similar units on the Moon or Mars.

A working hypothesis for the tectonic/volcanic chronology of Mercury was outlined by D. Dzurisin (Hawaiian Volcanic Observatory). Before the end of heavy bombardment, according to the chronology, tidal despinning plus global contraction combined to

produce a global pattern of linear crustal joints. Contraction continued after despinning, leading to arcuate thrust and/or high-angle reverse faults. Most intercrater plains predate both the end of heavy bombardment and the formation of most arcuate scarps. The Caloris basin-forming event was a significant marker in Mercurian history, leading to intense modification of antipodal regions, to smooth plains formation, and to subsidence-induced ridges and later uplift-related extensional fractures within the basin, and to scarp and ridge formation outside the basin due perhaps to gravitational readjustment to plains emplacement.

B. M. Cordell (University of Arizona) argued that the lobate scarps are primarily due to global contraction rather than despinning, citing three reasons. There are no large scale tensional features, in particular at the poles, such as would be expected if despinning has been the dominant stress-producing mechanism. The area density of scarps is not a strong function of latitude, excluding the paucity of scarps at the latitudes of the hilly and lineated terrain antipodal to Caloris, an anomaly probably caused by destruction of scarps by the Caloris event. Finally, the scarps appear to show a random orientation, except for a deficiency in nearly E-W scarps at latitudes less than 40°, probably a bias due to lighting rather than an actual preferred orientation.

P. Masson and P. Thomas (University of Paris-Sud, Orsay) mapped large lineaments in four Mercury quadrangles (H.1, H.3, H.7,

H.8) and concluded that the predominant lineament directions are radial to or concentric with the Caloris basin. Whether the observed lineaments were newly formed or were reactivated by the Caloris impact is an open question.

D. H. Scott and C. D. Condit (USGS) measured the density of intermediate-sized (3-10 km) craters on various geologic units on Mars to compare relative ages with those determined from the time-stratigraphic mapping of Scott and Carr. In general the relative ages determined by the two methods are in good agreement. One major anomaly is that the Tharsis volcanic plains are mapped as comparable in age or somewhat older than smooth plains, yet have much lower crater densities.

A detailed stratigraphic and crater chronometric study of the sequence of major geologic events in the northern Tharsis bulge region of Mars was presented by D. U. Wise (University of Massachusetts). Tharsis tectonics involve a complex sequence of arching, uplift, faulting, and volcanism extending over a large range of geologic time. Calibrating the measured crater densities according to the Neukum-Wise scheme, the Tharsis tectonic events lasted from 4.1 to 2.5 b.y. ago.

R. Goldstein and his JPL colleagues summarized recent Goldstone radar imaging and altimetry of the surface of Venus. The images portray a complex planet, including circular features suggestive of large craters, extensive plains with reflectivities suggesting boulder fields, and Martian-like chaotic terrain.

The prominent radar feature β at 24°N is probably a large shield volcano comparable in scale to Olympus Mons: a 600-km diameter base, up to 10 km in elevation, with a central depression 65 km in diameter.

In the abstract of a paper not delivered orally, V. R. Oberbeck (Ames Research Center) noted the deficiency of craters $<$ 50 km diameter in uplands on Mercury, Mars and parts of the Moon, with respect to extrapolations from the densities of larger craters and to regions on the Moon with many basin-associated secondaries. He explained this deficiency as due to a similar deficiency in the population of smaller impacting bodies during heavy bombardment of the terrestrial planets. Scaling crater production to different impact velocities and gravity fields gives comparable ages for lunar and Mercurian uplands, but yields a younger age for uplands on Mars.

Spectrophotometric Techniques and Studies

J. Veverka, J. Goguen and M. Noland (Cornell) reported the results of attempts to describe the photometric properties of planetary surfaces by the Minnaert function. The Minnaert function describes the brightness of a surface by the empirical relation:

$I(i, e, \alpha) = B_o(\mu_o, \mu^{-1})^k$,

where: i = angle of incidence = arccos μ_o,

e = angle of emission = arccos μ,

α = phase angle,

B_o and k are the Minnaert parameters.

When k = 1 the Minnaert function reduces to the familiar Lambert Law. The applicability of the Minnaert function was studied for dark, intricate surfaces, bright surfaces, and glossy or glazed surfaces. In no case did the Minnaert function give an adequate description of the measured brightnesses of the surfaces over a range of angles. This work is significant because the Minnaert function has been used in analyzing spacecraft and telescopic images of planets.

Evidence continues to accumulate that the Mariner 10 cameras, when operating at their design temperatures, can be used reliably for photometry. B. Hapke (University of Pittsburgh) used the Helmholtz reciprocity principle to analyze images of Venus in orange light and showed that the cameras are linear to about 1%. However, comparisons of images of Mercury taken on the second flyby, when the cameras were cold, with images taken on the first flyby, when the cameras were warm, showed that the decrease in temperature changed the calibration by about -15%. Also, as the phase angle of an area on Mercury decreases the normal albedo calculated using an average lunar photometric function decreases, indicating that the lunar function is probably too low at large phases. Thus the published normal albedos for various areas on Mercury are probably somewhat high. Mercury and the Moon both exhibit apparent

polar darkening on Mariner 10 images. This darkening can be completely accounted for by taking account of shadowing in craters, so that there is no evidence for a real dependence of normal albedo on latitude on Mercury. However, the solar wind flux is very likely to be quite non-uniform on Mercury between equator and pole because of the planet's magnetic field. If the solar wind were the agent primarily responsible for lunar and Mercurian soil darkening, such a non-uniformity should be reflected in albedo variations. Thus the primary soil-darkening process probably does not involve the solar wind.

L. Lebofsky and J. Conel (Jet Propulsion Laboratory) reported on their progress in measuring optical constants of ices in the IR. Problems of growing ice surfaces of optical quality have been overcome, but cloudiness of samples, probably due to impurities, is presently limiting the results. Diffuse reflection spectra of various frosts have been measured in the IR and used to infer the presence of either water ice or water of hydration on Callisto (J IV).

Asteroids, Comets, and Moons

Three contributions by F. Whipple, B. Marsden and F. Sekanina reviewed the recent progress of cometary research at Harvard's Center for Astrophysics. F. Whipple finds that ten short-period old comets exhibit the properties of H_2O ice sublimation

via their non-gravitational accelerations radial to the Sun and their albedo-area brightnesses at great solar distances. Several are quite "spotty", exhibiting less acceleration than an ice covered surface. Perhaps all are partly covered with meteoroidal debris and actually are activated by ices less volatile than H_2O ice. Certainly the outer layers of new comets show extraordinary activity, perhaps initiated by cosmic rays in distant space for 4.6×10^9 yr. The accumulated ion production near the surface amounts to some 50,000 cal/gm, or 80 times the heat of vaporization of H_2O ice.

B. Marsden continues his precision calculations of definitive comet orbits for long-period comets solving also for non-gravitational effects. Some 60% of the 111 most accurate orbits had their initial 1/a values clustered within 40×10^{-6} $(AU)^{-1}$ of the parabolic limit corresponding to escape velocities at aphelion of about 1m/sec. Thus the Oort comet cloud is clearly delineated. The comets of large perihelion distance show the effect most strongly as they are less affected by non-gravitational forces. Ninety-seven comets with second-class orbits show the effect less strongly. Only about 40% of the more than 500 long-period comets are well enough observed to give accurate values of 1/a.

F. Sekanina has discovered a new approach to the study of motions of split comets, based on the assumption that two fragments of a comet separate at a rate that is determined primarily

by a slight difference between their effective solar attractions and not by a large initial velocity of separation. The net dynamical effect is interpreted as due to differential non-gravitational forces, which depend on the size, density, structure, composition and spin rate of the fragments. The calculations show that this approach provides good to excellent fits of the observed separations for almost all of the split comets. The observed lifetimes of the fragments correlate strongly and inversely with the differential non-gravitational forces, strong support for the physical principles postulated.

C. Chapman, D. Davis, and R. Greenberg (Planetary Science Institute) reported on their new models of asteroid fragmentation processes and collisional evolution. These ideas have evolved considerably since the 1960's when Kuiper, Anders, and others viewed the "bump" in the asteroid magnitude-frequency diagram as suggesting that only the relatively small asteroids are collisional fragments. Asteroid cross-sections are now known to be much larger than was previously thought, due to advances in measuring asteroid albedos. In 1975, Chapman and Davis reported collisional models showing that all but the very largest asteroids must be collisional fragments and suggesting that the asteroids might be a remnant from a vastly larger population of precursor bodies. Hypothesizing that the so-called S-type asteroids are mantle-stripped stony-iron cores of differentiated bodies, they even suggested an estimate of 300

times the present population for the early asteroid population.

The early asteroid models were consistent with the then-best evidence on the log-log size-frequency relation for the C (carbonaceous) and S (stony-iron) asteroids, with a straight-line (power-law) distribution for the C's, indicative of thorough collisional fragmentation of weak bodies and non-linear distributions for the supposedly incompletely fragmented, strong cores. But new bias-corrected asteroid statistics by Bowell and Zellner suggest that C asteroids have a non-linear size distribution on the log-log plot.

Meanwhile, the Planetary Science Institute group improved several aspects of their collisional modelling. (1) Simultaneous collisional interaction of two distinct populations of bodies of very different strengths were modelled, simulating the C and S objects. (2) Laboratory data were employed to model the size of the largest and second-largest fragments in a catastrophic collision event as a function of the energy input to the target body by the projectile. They have found that many large weak (C-type) asteroids are fragmented by relatively energetic impacts that are nevertheless insufficient to disrupt the bodies against their own self-gravities. When more energetic impacts eventually disperse such already-fragmented bodies, the fragments are very small, resulting in a relative dearth of mid-sized C-type asteroids, consistent with the new size-frequency data.

Some computer runs have successfully reproduced the essential features of the currently observed distributions, even for grossly augmented initial populations. But Chapman et al. are further revising the collisional model prior to investigating the effects of varying the input parameters to determine the range of initial conditions and physical parameters consistent with the currently observed asteroid belt.

E. Shoemaker and E. Helin (CalTech) have continued their search for faint Earth-crossing and Mars-crossing asteroids. The accumulated data are being used to determine the present impact cratering rates for Mars, Earth and the Moon. For Venus and Mercury, the determination can only be made approximately since it involves a very uncertain correction for impacts with asteroids whose aphelia lie within 1 AU. The rates are expressed in terms of the production of craters 10 km in diameter or larger per unit area of surface. The relative rates at the present time are found to be equal for Mars, Earth, and Venus, and lower by a factor of 2 for Mercury and the Moon. At the present time active comets appear to contribute insignificantly to these rates. Shoemaker and Helin estimate that the current rate of production of craters in the above size range by active comets is at least an order of magnitude less than that due to asteroidal objects.

J. Veverka (Cornell) reviewed recent developments in the study of the satellites of Mars by Viking spacecraft. In late February 1977, Viking Orbiter 1 made a series of close passages

within 100 km of Phobos during which a team headed by R. Tolson (NASA-Langley) obtained the first determination of the mass of the inner satellite. A preliminary reduction indicates a low density of about 2 g/cm^3. Meanwhile, the first adequate spectrum of Phobos has been obtained by piecing together Mariner 9 data between 0.2 and 0.4 μm, reduced by K. Pang (PSI) and Viking Lander measurements between 0.4 and 1.2 μm, reduced by J. Pollack (NASA-Ames). The resulting spectrum is similar to those of C-objects in the asteroid belt, and unlike those of basalts. The above evidence, a mean density close to 2 g/cm^3 and a C-type spectrum, added to the very low albedo of Phobos ($\sim$ 6%) suggests a composition similar to that of the most primitive C-chondrites. If this suggestion is supported by detailed analysis, the implication would be that Phobos formed in the asteroid belt since current chemical condensation models predict that volatile-rich C-1 material formed only in the outer half of the asteroid belt and beyond, and not at the distance of Mars from the Sun.

The Viking Mission has produced images of Phobos with a resolution as high as 3 meters, and has led to a number of important discoveries. For example, a material considerably darker than the mean albedo of Phobos ($\sim$ 6%) has been discovered on the floors and in the walls of some craters. For several years polarimetry and infrared radiometry have suggested that material about 50% darker than the average albedo of Phobos exists in the asteroid belt. The Viking images provide the first direct confirmation of

the existence of such ultra-dark materials in the Solar System. Other unusual surface features revealed by the high resolution coverage are long chains of irregular craters which may have been produced by ejecta from Phobos which re-impacted the satellite after escaping from it and orbiting Mars for some time, and swarms of almost parallel grooves or "striations", which are very suggestive of tensional faults possibly produced by Martian tides. The Viking images show that the density of impact craters on the surface of Phobos follows the Hartmann "saturation curve" at least down to diameter of 30 meters.

Cratering as a Process, Landform, and Dating Method

G. Neukum (Max Planck Institute) and D. Wise (Univ. Mass.) have studied the crater size distribution of Mars on Mariner 9 pictures and derived a possible cratering chronology linking the martian to the lunar crater data. The impact crater production size-frequency distribution of Mars was found similar to that of the Moon for crater diameters in the range of 0.8 to 50 km, and it appears to have been relatively stable through time. The lunar and martian crater curves can be brought into near coincidence by a diameter shift of a factor of 1.5 appropriate to reasonable impact velocity differences between bodies impacting the two planets. This indicates that a common population of bodies impacted both planets

and suggests the same or a very similar time dependence of impact flux. The new scale suggests an orderly evolution, with Mars like the Moon winding down most of its major planetary tectonic and volcanic disturbances in the first 1.5 billion years of its history.

A. Woronow (Univ. Arizona) developed a computerized Markov Chain technique for simulating large-crater populations, and presented the following major conclusions: (a) Even the most densely cratered lunar highlands have not attained the saturation or equilibrium limit for craters >7 km diameter. (b) The production function for the lunar craters in the diameter range 7 to 1270 km closely resembles the highly structured size-frequency distribution actually observed, and not a uniform -2.0 slope index as often assumed. (c) The battered and degraded appearance of the lunar highlands' large-crater population is characteristic of the -1.2 to -1.3 production slope index ($7<D<56$), even at subequilibrium crater densities. These studies indicate that the large-crater population of the lunar highlands will appear quite degraded (as it does), but still have a crater density well below the saturation or equilibrium limits and retaining the essential features of its production function.

D. Gault (Murphys Center of Planetology) and J. Wedekind (NASA Ames) presented results of experiments to determine gravity effects on impact crater formation. Crater dimensions (both

diameter and depth) were found to vary with the inverse 1/6 power of gravitational acceleration. Crater formation times varied with the approximately 5/8 power of "g." These experimental values contrast with, respectively, 1/4 and 5/8 power relationships associated with so-called gravity scaling conditions for which the target medium has zero strength. The difference between 1/6 and 1/4 appears to be attributable to a small effective deformational strength of the quartz sand as indicated by the collective results of these experiments and small scale explosive crater studies. Such effects of small, but nevertheless finite, strength have minimal effects on formation times, but seem to suggest that "pure" gravity scaling (or 1/4 root dependence) can never be realized for normal conditions with geologic materials on planetary bodies.

E. Smith and J. Hartnell (Univ. Wisconsin-Parkside) reported on the effect of non-gravitational factors on the shape of planetary craters. They showed that there are significant differences in the terrace-size and central peak-size relationships for different terrains on Mars and on the Moon. Mercury on the other hand shows no significant differences in the crater shape-size curves between terrain types. Several crater morphologies are unique to Mars and may reflect unique target properties. For example, central pits and flow-like ejecta are associated with many craters. These features may be due to impact into a target con-

taining a permafrost layer.

G. Schubert, R. Lingenfelter (UCLA) and R. Terrile (CalTech) reported on the trends of crater degradation on the planets. The morphologic evolution of lunar and terrestrial craters can be modelled by a combination of filling and slumping processes. Martian crater evolution, however, cannot be understood on the basis of these two classes of crater modification alone. Instead, a process such as aeolian erosion which removes material from the crater rims, must have been the principal form of modification, and evolutionary tracks based on such a model coupled with weak aeolian deposition within the crater can indeed fit the martian data.

M. Cintala, J. Head, C. Wood, and T. Mutch (Brown Univ.) reported on interplanetary comparisons of fresh crater morphology and the factors affecting the morphology. For fresh craters formed on the lunar maria and highlands, they documented differences in the occurrence of central peaks, terraces, and scallops, indicating that target properties may contribute to observed differences in morphologies of craters on the Moon, Mercury, Mars, and Earth, and that potential substrate variations must be investigated before comparisons of entire planetary crater populations can be made. Additional conclusions included (1) The similar morphologies of craters formed in mare and smooth plains imply that the major differences in gravity (and probably modal impact velocity) for Mercury

and the Moon have not dominated the formation of crater morphologic features, (2) the mare-smooth plains similarities support the interpretation that mercurian smooth plains are of volcanic origin, and (3) the large differences in morphologies of craters formed in cratered terrain and highlands imply that those two terrain units have dissimilar physical properties.

C. Wood, J. Head, and M. Cintala (Brown Univ.) also compared crater degradation on Mercury and the Moon. For mercurian craters there is a systematic decrease in the percentage of craters with satellitic craters, central peaks, wall slumps, continuous and raised rims, and apparent depth from fresh (class 1) to degraded (class 5) craters. Impact cratering is the dominant degradational process on Mercury. The formation of smooth plains caused intense local obliteration and degradation of craters. Similarity in degradation trends for lunar and mercurian craters suggests that similar processes of degradation affected both planets; however, in detail, central peaks and terraces are better preserved in mercurian craters than in their lunar counterparts.

A. Carusi, M. Fulchignoni, M. Poscolieri (Italian CNR) and R. Cassacchia (Univ. Rome) discussed the morphological characterization of large mercurian craters and showed how craters vary with geographic region. Studies are underway to determine causes of these variations.

H. Hughes, F. App (Los Alamos Sci. Lab) and T. McGetchin

(Lunar Science Institute) studied the global seismic effects of basin-forming impacts. The principal results indicate that (1) far-field effects are largely independent of cratering mechanisms; (2) antipodal seismic effects are significantly enhanced by focusing and are of substantial magnitude. Vertical ground motion may be on the order of kilometers, and accelerations approach one lunar-g; (3) the most violent activity occurs at significant depth beneath the antipode; (4) seismic effects are decidedly more pronounced for a molten planet than for a solid one; (5) tensile failure may occur at depths of tens of kilometers beneath the antipode, and may also occur over the entire surface, although at shallower depths.

J. McCauley (USGS) reported on multi-ringed basin studies on several planets, with emphasis on the mercurian Caloris basin and lunar Orientale basin. Orientale and Caloris have more in common than previously realized. The basin fill in Caloris is, however, different from that seen in Orientale, being thicker. The Montes Rook and the main Caloris scarp are similar structural features. They mark the edge of the crater of excavation at each basin. Lineated ejecta derived from shallower horizons is present near and beyond the weakly developed outer Caloris scarp which is the counterpart of the Orientale scarp. A well-developed field of secondary craters lies at about one basin diameter around Caloris.

R. DeHon (Univ. Arkansas-Monticello) discussed a model for formation of multi-ringed basins in multi-layered media. On the basis of the model, he proposed that spacing of rings in multi-ringed basins is a function of layer thickness; the number of rings is dependent on the number of layers penetrated; shelf elevations are approximately equal to the elevations of the discontinuities; central peaks probably form by rebound; whereas, inner rings form by excavation and deposition; rings are composed of different materials from different layers; inner crater dimensions approximate the depth to diameter relationships of bowl shaped or flat floored craters; and the volume of ejecta from a multi-ringed basin is considerably less than that of a normal crater with the same diameter.

F. Hörz (NASA-JSC) and V. Oberbeck (NASA-Ames) discussed the continuous breccia deposits of the Ries Crater, Germany and suggested certain constraints on emplacement mechanisms which are consistent with a ballistic mode of ejecta emplacement. The energy required for excavating local materials, for intense and thorough mixing, and for final emplacement by a debris surge is supplied by ballistic ejecta.

P. Schultz (Lunar Science Institute) and Don Gault (Murphys Center of Planetology) analyzed the effect of the martian atmosphere on ballistic impact ejecta. They found that aerodynamic drag under present martian atmospheric conditions will affect significantly ejecta smaller than 1 cm; significant sorting of ejecta

with range by particle size may occur; considerable amounts of ejecta impact close to the crater rim for craters larger than 1-5 km but little aerodynamic effects occur for craters smaller than 1 km (even greater effects should be evident if atmospheric pressures had been greater in the past); and ejecta from large craters may be trapped within the crater following rim collapse. Such trapping should produce craters shallower on Mars than on Mercury or the Moon, as observed.

E. Guinness and R. Arvidson (Washington Univ.) analyzed the role of impact processes in the formation of the martian regolith. The block size-frequency distribution for parts of the Lander 1 site is denser than even the population found on large, fresh lunar craters, notably Tycho. Tycho is 100 m.y. old and not enough time has elapsed for much block destruction. However, in the vicinity of Lander 1, no such crater exists. Because of the atmosphere on Mars, small meteoroids are shielded out and the lunar-impact gardening that destroys blocks does not occur. If wind erosion rates are low, a block population could conceivably accumulate that mimics the fresh populations on the Moon. Preliminary estimates of the populations thrown in from a crater population (with a cutoff at 50 m) show that there are more blocks present than can be accounted for solely by impact. Rather, the blocks consist of impact material, and blocks weathered in-situ out of bedrock.

Physical and Chemical Characteristics of the Martian Regolith

A special session was held on the characteristics of the Martian soil layer interpreted from Viking spacecraft observations and measurements. The complete papers on these important results have recently been published in Science and Journal of Geophysical Research. (Science, Aug. 27, 1976, Vol. 193, No. 4255; Science, Oct. 1, 1976, Vol. 194, No. 4260; Science, Dec. 17, 1976, Vol. 194, No. 4271; Jour. of Geophysical Research, Sept. 30, 1977, Vol. 82, No. 28.)

Volcanic Processes

Volcanism is recognized as an important process in the development and evolution of planetary surfaces. Several investigations are in progress to understand better the mechanisms of volcanism and the styles of volcanism represented on planetary surfaces, as reported this year. These studies fall into two areas: (1) analyses of extraterrestrial volcanoes and (2) studies of Earth analogs.

A review of the results from Viking dealing with volcanism on Mars was presented by R. Greeley, representing the Orbiter Imaging Team. The evolution and sequence of events for the large shield volcanoes are seen to be much more complex than indicated from Mariner 9. Olympus Mons flows extend several hundreds of km beyond the

scarp onto the surrounding plains. Similar relationships are observed for Arsia Mons, where crater counts show a range in frequencies spanning a factor of 10 from the youngest flows near the summit to the oldest flows more than 1000 km to the south. Many "patera" have been imaged at high resolution. These apparently uniquely Martian volcanoes also are much more complex than previously thought and also appear to span a long period(s) of eruption. High resolution images reveal numerous small volcanic landforms on Mars, including small (approximately 10 km) constructs, cinder cones, and possible spatter cones.

Other aspects of planetary volcanism were reported in other sessions, including presentations by M. Malin, R. Strom, L. Soderblom, and D. Dzurisin on possible volcanic plains, magma generation by Solomon, and considerations of magma compositions by T. McGetchin, who suggested that the lavas on Mars may have been ultrabasic and hence extremely fluid.

Studies of volcanoes on Earth include three general regions: Hawaii, West Indies and Snake River Plain, Idaho. J. Lockwood, P. Lipman and G. Eaton (USGS) are investigating the southwest rift zone of Mauna Loa and other shield volcanoes in Hawaii and are attempting to derive the stratigraphic sequence for various flows. Geologic maps have been prepared for Mauna Ulu and Kilauea Volcanoes. A photogeologic study of the role of lava tubes and channels in the construction of shields in Hawaii was reported by

R. Greeley, C. Wilbur, and D. Storm (University of Santa Clara). More than 80% of the exposed flows on Mauna Loa included lava tubes and channels.

G. Heiken and T. McGetchin (Los Alamos Scientific Laboratory and the Lunar Science Institute) reported on their studies at LaSoufriere, an active silicic volcano in the West Indies. Eruption activity consisted primarily of fumaroles and lahar flows, with major finding that no magmatic tephra was erupted. Most of the activity appears to be related to relatively shallow groundwater circulation and the resulting phreatic eruption of hydrothermally altered rocks.

Volatiles, Climate Change, and Fluvial-like Features

In his report entitled "Volatile Evolution", F. Fanale (JPL) summarized the evidence for an evaporite-covered surface of the Galilean satellite Io. Recent laboratory studies of the reflectance spectra of various mixtures indicate that the best match to Io's spectrum is obtained by combining salts like alkali nitrates, sulfates and carbonates with elemental sulfur. Quite interestingly, recent observations at the University of Hawaii of the first deep absorption bands in Io's spectrum also seem to indicate the presence of these salts. Studies of rare gases on Mars have focused on the problem of the low Xe:Kr ratio in the Martian atmosphere as compared to that of the "planetary primordial" rare gas. There are strong reasons to believe that the depletion of Xe is a result of adsorption on the basaltic regolith of Mars.

Fanale has also constructed a quantitative model for the exchange of CO_2 between the Martian regolith and atmosphere. The model is based on laboratory experiments under simulated Martian conditions and seems to imply that the contents of atmospheric-exchangeable CO_2 in the regolith (which may be as high as 600 g/cm^2) is the major determinant of long-term (more than 10^6 years) climatic change. By keeping the total amount of CO_2 in the atmosphere-regolith system constant and raising the temperature on Mars by about $40^{\circ}C$ for a period of 10^5 to 10^6 years, one will produce an equilibrium atmospheric pressure of, at the most, 25-35 mb. Since this is the time span of temperature fluctuations due to obliquity changes, one must conclude that processes other than obliquity variations were required to induce past climatic conditions favorable to, for example, channel formation.

Theoretical studies on climatic change over geologic time on Mars are currently conducted by J. Pollack (NASA-Ames). In his report, entitled "Climatic Change on Mars: Inferences based on Viking and Mariner Data", Pollack presented results of calculations aimed at an understanding of the conditions that would cause the surface temperature on Mars to exceed the melting point of water. To achieve this with an atmosphere composed primarily of CO_2, would require a surface pressure in excess of 1 bar. This in turn, requires an atmospheric CO_2 content close to the total amount outgassed over the lifetime of Mars. If, in addition, we want to

account for the CO_2 adsorbed in the regolith, it becomes impossible to obtain the desired temperature regime on Mars with an atmosphere containing fully oxidized gaseous species.

Assuming an early reducing atmosphere on Mars, containing a little carbon dioxide as well as methane and ammonia, one can calculate that greenhouse effects could have generated equatorial and mid-latitude temperatures exceeding the melting point of water. A possible time for the occurrence of such an atmospheric composition would have been during the formation of the oldest volcanic plains. Age estimates of the ubiquitous equatorial gullies by Pieri indicate that these may indeed have formed at the time of emplacement of the oldest volcanic plains of the northern hemisphere. The gullies, therefore, may represent a time of milder and wetter Martian climate.

In a paper entitled "Carbonate Formation on Mars", M. Booth and H. Kieffer (UCLA) present the initial results of a laboratory study aimed at an evaluation of the importance of carbonate formation to chemical weathering on Mars. Carbonate formation was induced on finely powdered tholeiitic basalt, illuminated in an experimental atmosphere. The preliminary results indicate a typical rate of carbonate growth of about 10^{13} molecules cm^{-3} sec^{-1} at 100 mb CO_2 pressure. The rate of growth appears to depend on the partial pressures of CO_2 and H_2O and the particle size of the soil. Con-

tinuation of these experiments may provide valuable insight into mechanisms of regolith storage of outgassed CO_2.

The idea of ice-covered channels as a means of conducting small water discharges over long distances under present atmospheric conditions on Mars was evaluated by D. Wallace and C. Sagan (Cornell) in their paper entitled "Evaporation of Ice-Choked Rivers: Application to Martian Channels". Calculations indicate that an ice-cover, about 1 meter thick, would quickly form on the stream surface due to evaporative cooling. The surface evaporation rate would then become sufficiently reduced to permit under-ice flow for hundreds of kilometers.

In a presentation entitled "Viking Orbiter Imagery of Channels and Valleys", M. Carr (USGS) reviewed the evidence for large-scale flooding seen along the margin of Chryse Planitia, primarily at the mouth of Areas Vallis, near the originally selected A1 landing site. Streamlined hills and sinusoidal channels argue strongly in favor of catastrophic flooding. Evidence of excavated valleys with a central depression indicative of a stream channel and its associated "flood plain" has been found near some of the larger basins in the southern hemisphere.

In his paper: "Preliminary Statistical Analysis of some Martian Channel Networks", D. Pieri (Cornell) presented results indicating that the small channel networks, ubiquitously distributed on the old cratered terrain on Mars, have a topology

similar to very immature terrestrial river systems. The old age of these small channels, demonstrated by Pieri's earlier studies, combined with this new evidence of a rather short period of fluvial valley cutting are consistent with the hypothesis of an early Martian atmosphere, permitting the surface existence and, perhaps precipitation, of liquid water.

B. Lucchitta (USGS) reported "A Large Landslide on Mars" observed in Viking orbiter pictures of the south wall of Gangis Chasma. Geometry and surface morphology of the slide deposit suggest that emplacement was very efficient. Perhaps the slide was lubricated by a cushion of water or steam released from ice in the source rock of the landslide by the heating action of the motion.

Two presentations dealt with terrestrial analog channels. V. Baker (University of Texas at Austin) in a talk entitled "Viking - Slashing at the Martian Scabland Problem" argued that landforms in southern Chryse Planitia, especially near the proposed A1 landing site, are analogous to erosional features created by the late Pleistocene catastrophic Missoula flood across the Columbia Plateau. The channels debouching onto Chryse Planitia to the west of the VL 1 site are also thought to represent catastrophic flooding. The water was temporarily ponded upstream of transverse ridges and scoured deep channels through their downstream flanks. Baker presents the working hypothesis that many

channels extended headwards by the progressive transformation of water-saturated fractured rock into chaotic terrain. Water might have b en present as a permafrost or clathrate in the regolith.

P. Komar and C. Reimers (Oregon State) pointed out interesting morphological similarities between outflow and run-off channels on Mars and channels commonly cut into submsrine fan sediments as an extension of the terrestrial submarine canyons. These channels are formed by catastrophic turbidity currents. The channel-forming process differs from that of subaerial flows because the effective gravity is less. In terms of the driving component of the effective gravity force, surface flows on Mars would be intermediate between subaqueous turbidity flows and rivers on Earth. Liquid flow on Mars should clearly be studied with the effects of the different gravity field in mind.

Eolian Processes

Results presented in the eolian section and extended abstracts dealing with eolian activity centered about three areas: (1) Interpretation of Viking observations of apparently eolian process and products, (2) Earth analogs of features on Mars that are probably eolian in origin, and (3) Experimental studies designed to simulate eolian activity on Earth and Mars.

C. Sagan (Cornell) noted that discrete drifts or accumulations of fine-grained material are more abundant in Chryse Planitia as opposed to Utopia Planitia, as seen by the Viking Lander cameras. He noted that direction of tails of sediments extending downwind from cobbles and boulders, as measured by E. Guinness (Washington Univ.), point in a southwesterly direction at approximately the same azimuth as bright streaks seen from orbit. The implication made by both Sagan and Arvidson (Washington Univ.) is that both features formed during the same winds, perhaps during the global dust storm that occurs after perihelion. J. Veverka (Cornell) and Greeley (Arizona State Univ.) noted that dark streaks at Chryse Planitia, on the other hand, are oriented almost 180° away from the bright streaks. Sagan also noted that the high cohesion of soil at both landing sites implies a turn-up at small sizes in the threshold velocity - particle diameter curve. Arvidson and Sagan pointed out a significant lack of sand

sized particles - those particles that are too large to be carried away in suspension, but rather bounce and skip along the surface. Without sand, eolian abrasion rates should be considerably reduced compared to, say, the Earth's sandy deserts. Such a conclusion is consistent with that inferred by R. S. Saunders (JPL), who noted that rocks at both landing sites are angular and appear to have been fractured out of bedrock with little subsequent modification. Guinness and Arvidson found that craters of $\lesssim 50$ meters in diameter are not present at either landing site, even though the crater population appears to be in production down to the orbital camera resolution limit of 300m at Chryse Planitia. Such a result is consistent with ablation and breakup of incoming meteoroids by the martian atmosphere - objects capable of producing craters $\lesssim 50$ meters in diameter are consumed. There is no need to call upon any crater obliteration by surface processes to explain the crater size-frequency distribution. Conversely, such a well-preserved crater population implies a low rate of eolian and other erosion and burial over the lifetime of Chryse Planitia.

R. Arvidson and S. Bragg (Washington Univ.), by utilizing reflectance data in the .4 to 1.0 μm range derived from Viking Lander camera data, found that most soils have similar spectra, with a deep absorption band centered at 0.93 μm. Such spectra are indicative of Fe-rich mineral phases. One significantly different

spectrum was obtained for a drift of dark material lying amidst a field of dark rocks at Chryse Planitia. This spectrum increased from blue to red, but showed only a very subdued absorption in the infrared. These results imply a global, though not complete, degree of mixing of at least the outer few centimeters of soil by Martian winds.

R. Greeley and co-workers, using the NASA Ames low-pressure wind tunnel facility, reported on threshold wind velocities needed to entrain particles under Martian conditions. They found that at 5.3 mbs surface pressure, wind velocities needed a few meters above the surface (to set in motion 160 μm particles) range from 50 to 135m/sec, depending on the surface roughness. They also found that 2-6% by weight of water absorped on particles catastrophically vaporizes when exposed to Mars pressures and winds. Such rapid vaporization is an additional energy source, causing particle jiggling and ejection. Electrostatic forces were found to be significant under Mars conditions. Experiments designed to simulate rates of erosion on Mars show that because of high winds and a comparative lack of atmospheric cushioning, eolian abrasion rates due to a saltating load are higher than for terrestrial case. Finally, both Greeley and co-workers, and Saunders, deduce that saltation path lengths will be longer on Mars than on Earth because of higher wind velocities and lower gravity.

J. McCauley (USGS) presented a progress report on 1 bar wind tunnel experiment in which topographic forms with varying physical properties were subjected to high winds. He found that the extent of erosion and the equilibrium topography were largely controlled by resistance to abrasion. Grain plucking was found to dominate the erosion process.

A. Howard (Univ. of Virginia) advanced the hypothesis that the topography of the polar layered deposits is controlled by the magnitude of insolation received, which is in turn controlled by the slope magnitude and tilt direction. Howard also noted that accumulations of wind-blown material occur when: (a) atmospheric wind flow converges, (b) wind shear stress decreases, and (c) surface roughness changes. He speculated that Mars may have few dunes compared to terrestrial deserts because Mars may lack extensive sand accumulations.

J. Veverka, J. Goguen, and K. Cook stated that contrary to the conclusion of Kuzmin (1975, Russian A. J. Letters, 1, 42), dark streaks do not appear dark because of imaging at large phase angles. Rather, both bright and dark streaks can be seen in the same Mariner 9 and Viking Orbiter frames, implying that bright and dark streaks are separate entities. They suggest bright streaks are depositional, while low latitude dark streaks are mainly erosional.

A. Cotera and C. McCauley (Northern Arizona Univ.) sampled

two dune fields in Arizona: the Painte dune field and the Cameron dune field. The Cameron field contains evidence for both an eolian and fluvial origin. They found that the difference between eolian and fluvial sediments is best expressed in the kurtosis (degree of spread in size) parameter of the sediment size-frequency distribution.

Instrument Development and Techniques

Experiments with Side-Looking Airborne Radar (SLAR)/ photogrammetric analysis were described by G. Schaber (USGS). The relationship between radar power, radar film density and small-scale surface roughness has been elucidated using studies of selected field areas. These studies include statistical determination of the probability-size-frequency distribution of surface irregularities down to mm resolution. This distribution was photogrammetrically derived for the Death Valley, California Salt Pan using a sophisticated terrain analysis computer program. The program provides estimates and statistical analysis for a variety of slope and roughness parameters. The quantized roughness data were related to nadir and off-track specular power data collected from an overflight of Death Valley in 1976. Preliminary models for radar backscatter power attributed to "pure" small-scale surface roughness were derived. This is essentially the first such systematic comparison between such an assemblage of statistical roughness parameters and SLAR data.

A Metzger , J. Willett (JPL) and H. Schnopper (SAO) pointed out that in-situ mineralogical analysis by X-ray diffraction attacks directly the problem of the formational conditions of the surface material. A "Seemann-Bohlin" type diffractometer has been designed specifically for this purpose. Advantages of this design over the conventional "Bragg" geometry include: (1) higher diffracted beam intensity per power output, (2) mechanical simplicity by decreasing the number of moving

assemblies to one from the two required by the Bragg geometry, (3) twice the lattice spacing resolution offered by the Bragg geometry for equivalent dimensions, and (4) lower weight and power requirements. A partial elemental analysis is made possible by adding a non-dispersion detector sensitive to X-ray fluorescence from the sample. Otherwise a sample splitter will allow the X-ray diffraction sample to be analyzed by an independent α/p/X-ray instrument. Goals include extending the range of the instrument to include large d-spacing minerals, and incorporating a stationary detector system. Because of the possible occurrence of high d-spacing (clay) minerals on Mars, an effort is underway to develop a radically new (spherical) geometry capable of raising the range to 20-22 Å. Metzger pointed out that, if successful, a rugged instrument would result, with no moving parts, capable of obtaining a diffraction pattern on an unlimited number of samples in about 1 minute each - an attractive instrument for a Rover payload.

A. Turkevich, T. Economou (Univ. Chicago) and E. Franzgrote (JPL) discussed methods of in-situ chemical analyses for future planetary missions. They pointed out that widespread in-situ chemical analyses on Mars seemed required by orbital and other remote sensing which suggested varied large geochemical provinces. The ability to analyze low atomic number elements and minor or trace elements is crucial. Improvements anticipated include lower instrument mass and less stringent demands on the cryogenic environment of the detectors. On a Mars rover, for example, an α/proton/X-ray instrument could provide a quick-look ($\sim$ 20 minutes)

survey analysis and could also provide a complete and precise chemical analysis if the sample is deemed of sufficient interest. A deployed instrument could analyze pristine, undisturbed natural surfaces which may have different compositions than bulk soil or rock. From the forebodies of several penetrators, some crucial subsurface measurements could be made. One such measurement would be total H content, which would help define the distribution of permafrost or hydrated minerals below the top two meters or so.

F. Fanale (JPL) discussed a soil water experiment for a penetrator forebody and an atmospheric water experiment for a penetrator afterbody. The first experiment is important because not only would widely separated sites on Mars be sampled, but also the "deep" (> 1 m) subsurface would be sampled. This would allow hard frozen permafrost to be measured even if it is not revealed to surface experiments owing to annual sublimation in the top 1 m during summer months. Besides just measuring the total amount of H_2O, this experiment would be able to distinguish H_2O in each of the following sites: ice, adsorbed H_2O, interlayer H_2O in clays, H_2O of hydration in salts or dydrated iron oxides, OH^-, etc. This would be exceedingly useful in estimating the total degassed H_2O inventory or "resources" of the regolith and also in defining the conditions under which regolith minerals formed. This could be accomplished by a P_2O_5 sensor element and associated electronics (both already shock tested several times at 17,000 g), coupled with a small calorimetric soil heating oven. The sample could be delivered to the system by a proposed upward drilling short soil drill with hollow flutes. On the afterbody, a similar sensor could

measure H_2O pressure at the surface - a crucial measurement that has not yet been accomplished - as a function of time.

J. Warner (Johnson Space Center) outlined a suggested post-Viking program of Mars exploration. Such a program should be designed to elucidate (1) the endogenic differentiation and degassing history of Mars, (2) its bulk composition, (3) its exogenic modification history, and (4) its possible biological history. He contended that the data most likely to serve as a continuing resource for the planetary science community are that which result from analyses of returned samples since these are performed with state-of-the-art analytical techniques which can be changed at the investigator's discretion in response to accumulating knowledge. Moreover, analysis can be preceded by elegant sample preparation. Separation of rock components can reveal a wealth of information not obtainable from unresolved mixtures of these components.

A. Albee (Cal Tech) pointed out that a proposed orbiter-penetrator-rover 1984 mission to Mars could be designed to accomplish the following objectives: (1) characterization of deep and near-surface internal structure, (2) characterization of global variations in surface geochemistry, (3) documentation of geomorphic and stratigraphic attributes of major landforms, (4) determination of chemistry and mineralogy of surface samples, (5) determination of the abundance and distribution of H_2O and other volatiles, (6) characterization of global atmospheric dynamics, and (7) characterization of the magnetic environment. Minimum payloads for these vehicles would be as follows: <u>Orbiter</u>: CCD cameras, gamma

ray spectrometer, reflectance spectrometer, radar altimeter, magnetometer, IR radiometer; <u>Penetrator</u>: 3-axis seismometer, α/p/X-ray spectrometer, X-ray diffractometer, reflectance spectrometer, diff. scan. cal./mass spectrometer, EM receiver, active seismic source, sample crusher and siever; <u>Rover-deployable package</u>: 3-axis seismometer, high frequency seismometer, magnetometer, meteorology (p, T, V), EM transmitter.

The rover should be a sophisticated self-contained scientific laboratory capable of roving over a distance of not less than 100 km. In addition to intensive studies at especially interesting sites like those a "soft lander" would execute, the rover can perform routine science measurements including imaging in a semi-autonomous mode during traverse. The rover will provide its own obstacle detection (using a laser rangefinder) and avoidance during a daily traverse. The rover will be equipped with an auger, a drill (capable of drilling up to 10 cm in rock) and a manipulator.

Additional Activities

Tharsis Workshop

A workshop to discuss the origin, evolution, and present state of the Tharsis province of Mars was convened in Vail, Colorado, on September 5-9. One of the major goals was to evaluate the Tharsis, volcanic-tectonic province of Mars in the context of evolving knowledge of terrestrial global tectonics. Roger Phillips of JPL was the chairman. Attendees represented both planetary and terrestrial geophysicists.

The first two days were devoted to review of current knowledge and the formation of the geological, geophysical, and petrological constraints regarding the time of uplift and faulting and the timing and nature of the volcanism. The final three days were used to formulate hypotheses of formation and to [illegible]ate those hypotheses against known facts, and to define research that can provide tests of the various hypotheses. The major hypotheses of origin that evolved from the discussions are: chemical plume, global convection, Hellas impact antipode, primordial inhomogeneities, core formation, and lithospheric overturn. These and other hypotheses will be tested by research activities of the group and progress will be reported at the next meeting in about 10 months. A short report of the meeting is being prepared for EOS and a more complete exposition of the constraints, hypotheses, and future research problems is being prepared for publication as a NASA TMX.

Crater Statistics Committee

A committee composed of twelve scientists deeply involved with the collection and analysis of crater statistics met in Flagstaff on September 8 and 9 to make recommendations for standards of crater measurements and statistical analysis methods. The committee recommended the following: (1) raw data should be included in tabular form in articles that present new crater statistics data; (2) the raw data should also be archived at a readily accessible location; (3) an index map or other method of locating and describing the boundaries of the sample area should be included when presenting new crater data; (4) both cumulative size-frequency distributions and percent area plots should be used to graphically represent the data; (5) error bars based on standard error should be included for each data point graphed; and (6) a quantitative estimate of fit should be included for curves fitted to the data. All of the recommendations were made unanimously by the committee. A summary of the results and recommendations of this meeting are being drafted and will be published in the open literature as well as a NASA document. A second meeting, which will also include several new committee members, is tentatively scheduled for the spring to discuss standards for crater morphology statistical studies.

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Recent developments in planetology research as reported at the 1977 NASA Planetology Program Principal Investigators meeting are summarized. Important developments are summarized in topics ranging from solar system evolution, comparative planetology, and geologic processes, to techniques and instrument development for future exploration.

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